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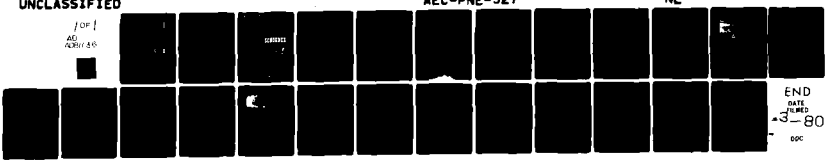

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DOCUMENT IDENTIFICATION

June 1970
Issued: January 1971

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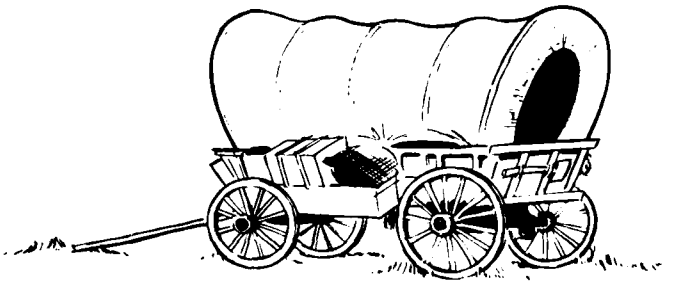
PNE-527

Plowshare civil, industrial and scientific uses for nuclear explosives

UNITED STATES ARMY CORPS OF ENGINEERS

PROJECT SCHOONER



FAR-OUT FALLOUT COLLECTION PROGRAM

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ISSUED: JANUARY 1971

PNE-527
TID-4500, UC-35
Nuclear Explosions –
Peaceful Applications

PROJECT SCHOONER
FAR-OUT FALLOUT COLLECTION PROGRAM

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Preface

The Far-Out Fallout Collection Program was a cooperative effort of the U. S. Army Engineer Nuclear Cratering Group (NCG), the Radiochemistry, Bio-Medical and K Divisions of the Lawrence Radiation Laboratory (LRL), and the U. S. Public Health Service (PHS)-Southwestern Radiological Health Laboratory (SWRHL). This program was carried out as part of the joint Atomic Energy Commission—U. S. Army Corps of Engineers nuclear excavation research program.

PROJECT SCOONER
FAR-OUT FALLOUT COLLECTION PROGRAM

Abstract

The Far-Out Fallout Collection Program was an experimental program to collect and to analyze samples of long-range fallout from Plowshare nuclear cratering events. Samples of fallout from Schooner, a 31-kt cratering experiment, were collected at downwind distances ranging from 65 to 500 km from the detonation site. The field operations required to obtain the fallout samples and the radiochemistry techniques used to analyze the samples are described. Measured values of the gamma exposure rate resulting from fallout at downwind locations in eastern Nevada and western Utah are reported. The maximum recorded exposure rate 65 km from the detonation site was 130 mR/hr. Of the 80 fallout samples collected, 16 were radiochemically analyzed to determine the species and quantities of radionuclides, present. The presence in each analyzed sample of up to 20 different radionuclides, including ^{90}Sr and ^{131}I, was determined. The radiochemistry results are expressed in terms of deposited radioactivity per unit area (pCi/m^2).

Contents

Introduction

Cratering with nuclear explosives releases small quantities of radioactive debris in the vicinity of the detonation and downwind. Most of this released radioactivity is deposited in the local fallout field shortly after detonation. However, radioactive particles less than 20 microns in diameter may be transported up to several hundred kilometers from the detonation site to be deposited as long-range fallout.

PURPOSE AND SCOPE

The objective of the Schooner Far-Out Fallout Collection Program was to collect and to radiochemically analyze samples of long-range fallout at distances ranging from 70 to 500 km from the detonation site in order to determine the magnitude and extent of the ground deposition of this fallout.

This report presents the following:

1. A description of the field operations required for sample collection
2. The laboratory procedures followed in the radiochemical analysis of the samples
3. The results of the radiochemical analysis giving the magnitude of deposition in pico-curies per square meter (pCi/m^2) of up to 20 different radionuclides at 15 separate downwind sampling locations

BACKGROUND

Much data on long-range fallout from tower and air detonations obtained during the continental weapon tests of the 1950's are available.[1,2,3] However, it was believed that the particle size distribution in clouds produced by nuclear cratering is sufficiently different from the distributions obtained from tower and air detonations, due to different detonation environments, to warrant an experimental program designed to obtain long-range fallout data from cratering detonations.

The Far-Out Fallout Collection Program was initiated in order to document long-range fallout from nuclear cratering events; it was begun on Project Cabriolet[4] and continued on Projects Buggy[4] and Schooner.

DESCRIPTION OF SCHOONER EXPERIMENT

Project Schooner was a nuclear cratering experiment in a layered tuffaceous medium executed as a part of the Plowshare Program for the development of nuclear excavation technology. Schooner was detonated on 8 December 1968 at approximately 0800 PST, at the Nevada Test Site (NTS). The resultant yield was 31 ± 4 kt. Surface ground zero (SGZ) was 1695.4 m MSL. The emplacement depth was 108.2 m. The emplacement hole was at geodetic coordinates:

Longitude — W116° 33' 57.1419"
Latitude — N 37° 20' 36.3187"

The detonation produced two distinct clouds whose dimensions at stabilization were:

Main cloud height	4000 m
Main cloud radius	1200 m
Base surge height	670 m
Base surge radius	2100 m

Initially, the base surge cloud traveled almost due north while the main cloud went towards the northeast. At later times the clouds traveled towards the east.

Field Program for Collecting Fallout Samples

This section presents a description of the fallout collector for the Far-Out Fallout Collection Program and the requirements used in its design and placement in the field. The personnel and organization required for placement of the collectors are also described. Maps are given showing where the fallout collectors were located relative to the Schooner SGZ. Gamma exposure rate measurements made at these collector locations are tabulated.

FALLOUT COLLECTOR DESIGN, FABRICATION, AND PLACEMENT

The collection of long-range fallout required the design of a fallout collector satisfying the following requirements:

1. A sampling surface large enough to collect sufficient radioactive debris for wet chemical processing and separation
2. A surface coating capable of retaining the debris impinging on it
3. A sampling surface of a type that the fallout could be quickly and completely removed so analysis could proceed efficiently
4. A collector which would lie flush with the natural ground surface to avoid airflow turbulence above the collector
5. A collector which would lie secure and stable in the high winds typical of the Nevada and Utah desert region
6. Contamination of the sampling surface before or after the sampling period must be avoided.

Based on these requirements, the following collector design evolved. A 9 × 12-ft canvas tarpaulin was used as a strong but flexible base to which a 7 × 10-ft polyethylene sampling sheet was cemented. A one-to-one mixture of petroleum jelly and toluene was applied to the sampling sheet. After evaporation of the toluene, the remaining sticky coating of petroleum jelly served to retain any fallout debris falling on it. A polyethylene cover sheet was placed over the sampling sheet to prevent contamination of the sampling surface. An assembled fallout collector is shown schematically in Fig. 1. The collector was then folded into a package about 2 ft × 3 ft × 6 in. and labeled with an identifying number (S1 to S100). Care was taken at all stages of collector fabrication to prevent any contamination of the sampling surface.

To place the collector in the field, the packaged fallout collector was unfolded and fixed to the ground by steel stakes driven through the edge of the canvas tarpaulin (see Fig. 2). The cover sheet was then removed to begin fallout sampling. At the end of the sampling period, the surface of the sampling sheet was folded onto itself and the edges were securely sealed to isolate the sampling surface from outside contamination. Then the sheet was folded into a small package (1 ft × 1 ft × 3 in.) and removed from the canvas tarpaulin. The folded sample was sealed in a plastic bag. To further minimize outside contamination, this bag was placed in another bag and sealed. The sample was then marked with the collector's identifying number.

CONCEPT AND EXECUTION OF FIELD OPERATIONS

The fallout collector described above is easily transported and can be quickly

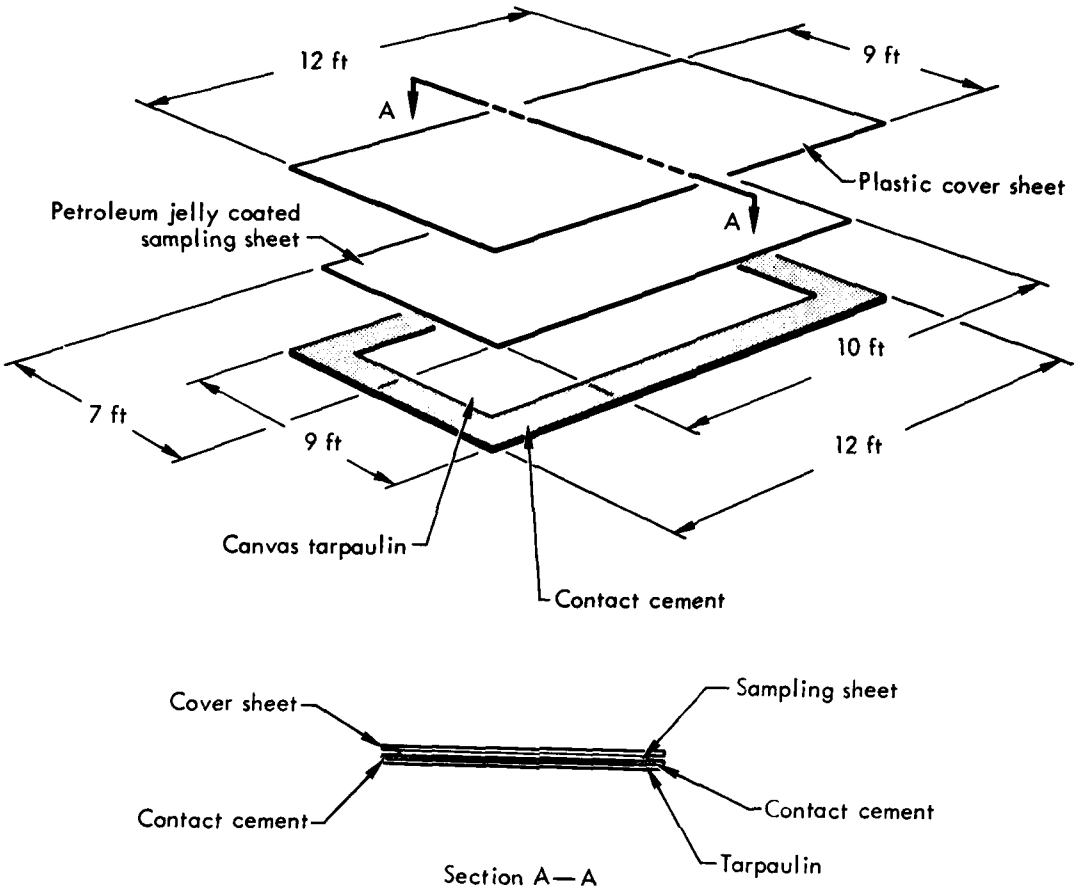

Fig. 1. Schematic drawing of assembled fallout collector.

set up in the field. These properties together with its low cost allowed development of a flexible field program for fallout sampling.

The expected fallout from Project Schooner was constrained by meteorological conditions to fall within an "acceptable fallout sector" (i.e., the area where off-site fallout would be permitted). The field program was designed to sample long-range fallout deposition within this sector at varying distances from SGZ to determine the dependence of deposition on distance. Of particular interest was the maximum deposition which would occur at these distances. Additionally, at a given distance, sampling perpendicular to the direction of cloud travel was desired so that the lateral extent and variation in magnitude of deposition along a cloud diameter could be determined. Therefore, fallout sampling should take place along predetermined arcs. However, to permit quick and easy access to any collector location, the fallout collectors were actually set up along highways which approximated these arcs. Figure 3 illustrates the Schooner acceptable fallout sector and the three predetermined arcs together with the

Fig. 2. Far-out fallout collector in the field.

major highways in eastern Nevada and western Utah.

Suitable collector sites for collector placement were selected by a predetonation reconnaissance of the fallout sector. To be deemed suitable a fallout collector site had to be easily accessible and located (1) on the upwind side of the road and 20 to 50 m from the highway to minimize dust contamination from highway traffic, (2) in a cleared area free of nearby obstructions (i.e., billboards, fences, signs, etc.) which would perturb the micrometeorology of the area, and (3) near an easily identifiable landmark to facilitate retrieval of the sampling sheet, especially in darkness. Most of the collector sites were referenced to nearby state or county highway mileage markers. Figure 4 shows a map of the fallout sector with the fallout collector sites indicated by the appropriate mileage marker designation. A similar map was used during the field operations to specify locations for fallout collector placement.

Nine field teams of two men each placed and retrieved the fallout collectors. The teams were supplied vehicles, communications equipment, fallout collectors, and portable scintillation rate meters. The meter sensitivity was such that the arrival of the radioactive cloud could be detected and the gamma radiation field due to fallout greater than background (4 to 14μR/hr) could be measured. Three teams were assigned to work on each arc.

These nine teams started field operations three days before the scheduled detonation day (D-3). From D-3 to D-2 they set up fallout collectors to sample background levels for approximately 24 hr at locations which spanned almost the entire acceptable fallout sector. The field teams also measured the background radiation levels and familiarized themselves with the suitable collector sites along their assigned arcs. Two control personnel were present in the project Control Point (CP) at the NTS on D-1 and D-day to coordinate all field operations. Communications between the CP and the field teams were maintained through the PHS radio network and public telephones.

About an hour before detonation, CP personnel instructed the teams on Arc 1 where and when to place their collectors. The CP personnel selected these locations by using Weather Bureau predictions of fallout direction and cloud travel time. Since cloud arrival time along Arc 1 was about 2 hr, collector placement had to begin prior to detonation to guarantee that

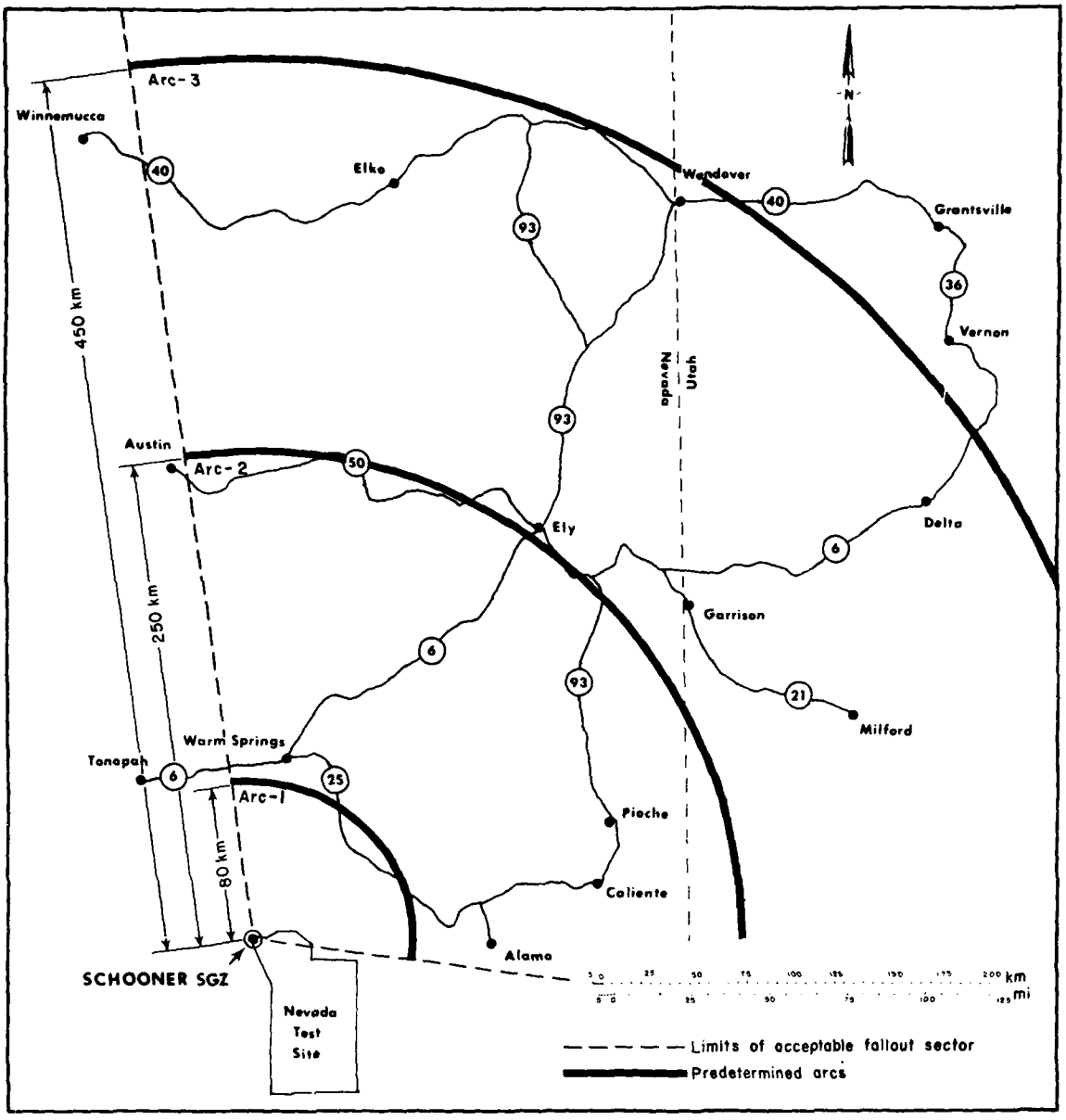

Fig. 3. Acceptable fallout sector and predetermined arcs.

all collectors would begin sampling before cloud arrival. After detonation, close-in monitoring results were used to determine locations for placement of additional collectors on Arc 1 to guarantee that sampling would occur on the "hot-line."

The monitoring results along Arc 1 were to be used by CP personnel to instruct teams on Arc 2 where to place their collectors. However, shortly after the clouds passed Arc 1, winds sheared portions of the clouds from the main body

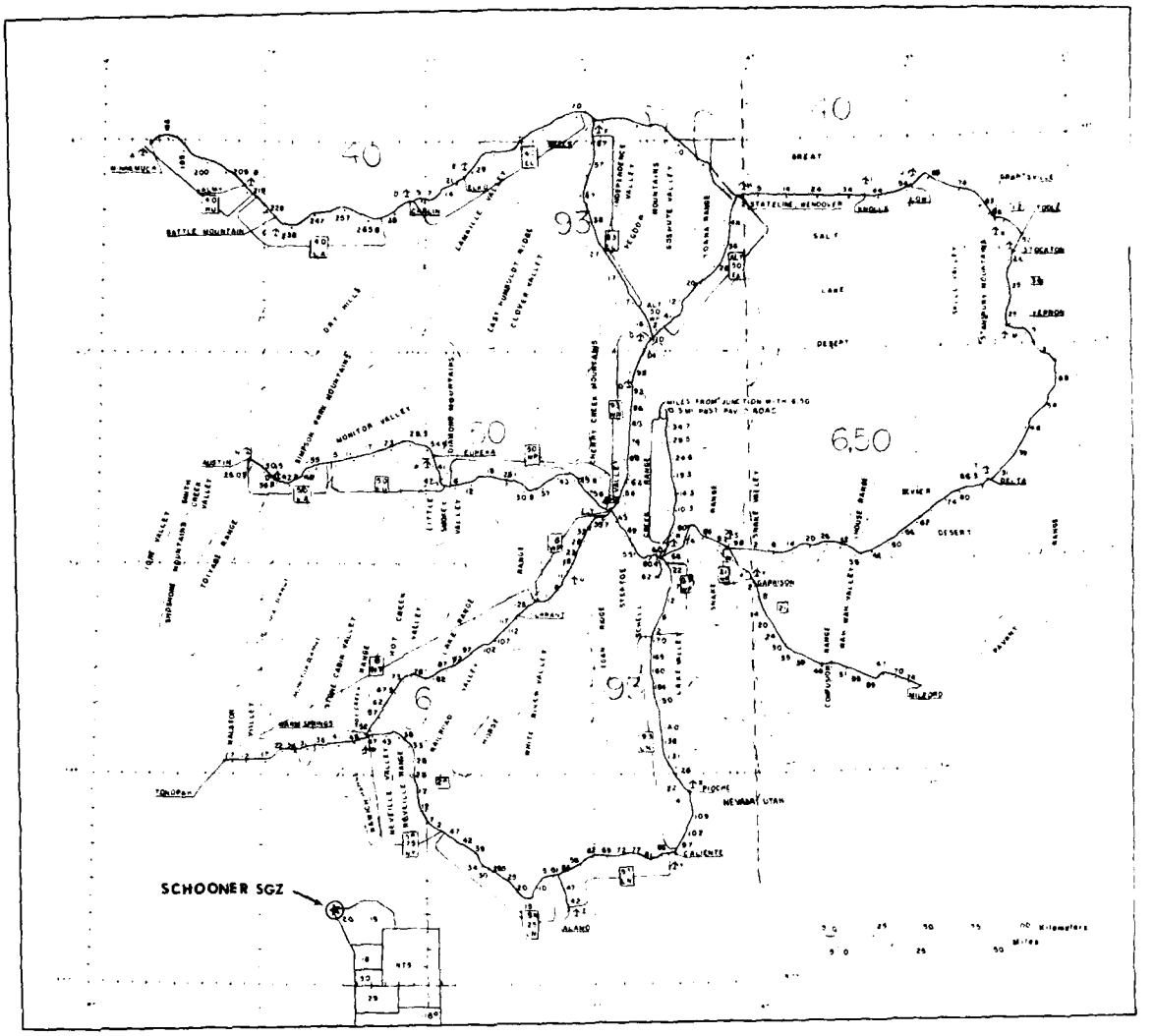

Fig. 4. Map of sites suitable for fallout collector placement (used by field teams).

of the clouds. As a result no attempt was made to increase the density of collectors along any given portion of the remaining two arcs. Instead the fallout collectors were deployed as widely as possible along Arcs 2 and 3 to insure extensive documentation of Schooner fallout.

Several hours after detonation, aircraft tracking of the cloud's trajectories indicated that movement of the clouds had slowed considerably. Therefore, to make certain that sampling was complete, the teams on Arcs 2 and 3 were directed by the CP to retrieve their sampling sheets on the following day. After retrieval, the fallout samples were sent to Mercury, Nevada for transshipment to LRL in Livermore, California.

RESULTS OF FIELD OPERATIONS

Eighty samples were retrieved of which 14 were background samples.

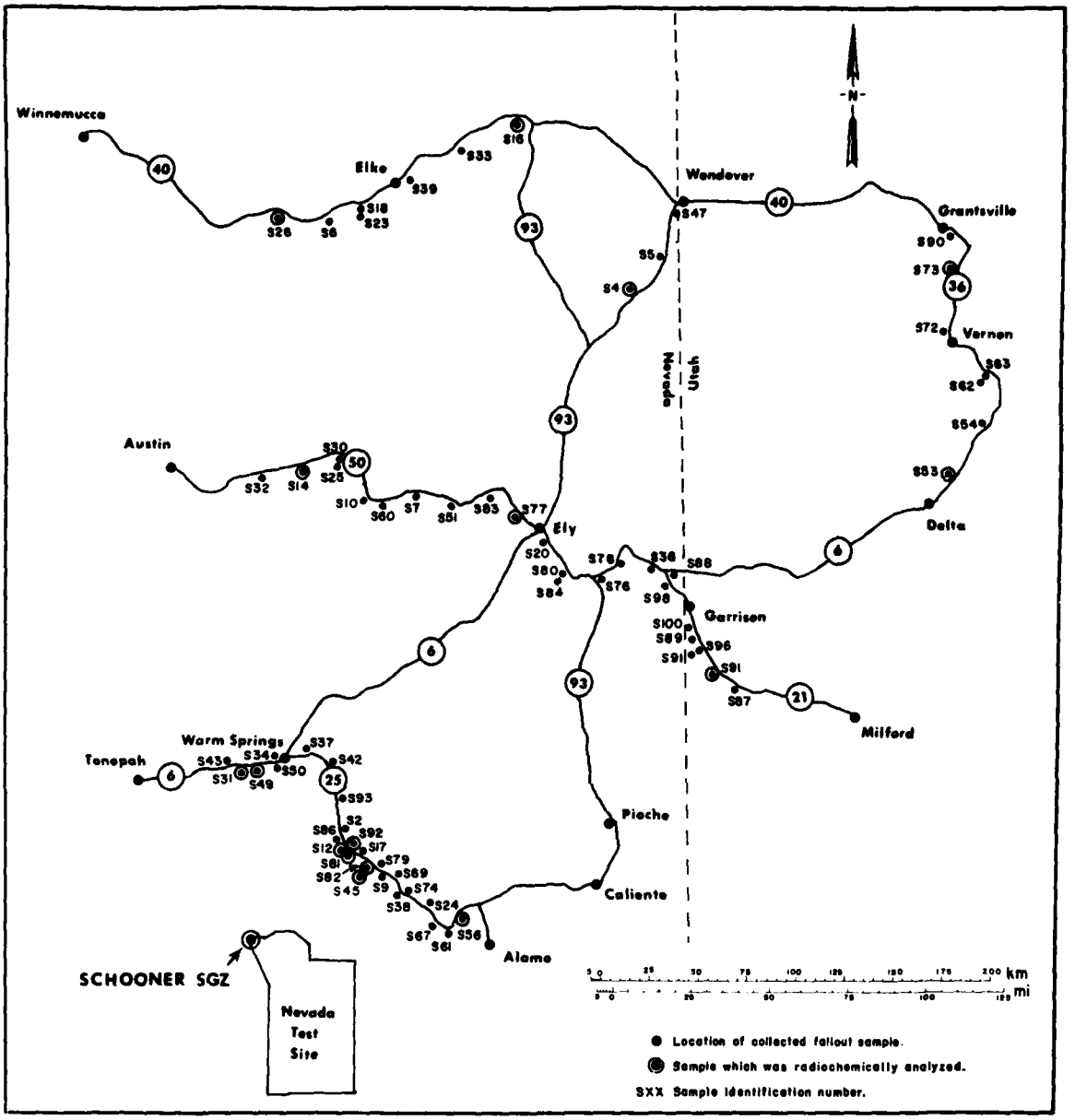

Fig. 5. Locations of Schooner far-out fallout collectors.

Their locations relative to the Schooner SGZ are shown in Fig. 5. Because poor communications between the CP and a field team on Arc 1 resulted in delaying the removal of seven cover sheets, sampling by these collectors began after arrival of the cloud.

Cloud arrival time was monitored by three of the nine field teams. The team closest to SGZ visibly observed the arrival of the cloud and saw particulate debris being deposited. Table 1 gives the measured times of cloud arrival.

Table 1. Measured cloud arrival times.

Location from SGZ		
Distance (km)	Azimuth (deg)	Time of arrival
76	60	0945 (H + 1-3/4)
280	51	1800 (H + 10)[a]
410	56	1900 (H + 11)

[a]This measurement was definitely not on the "hotline."

Gamma exposure rate measurements taken 3 ft above the fallout collectors, both at the beginning and at the end of the sampling period, are given in Table 2. These measurements ranged from 30 to 10^4 times background on Arc 1 and from 4 to 40 times background on Arc 3. However, the highest exposure rate measurements made on Arc 1 were made by an instrument contaminated by particulate debris.

Although the scintillation rate meters were useful in detecting cloud arrival and in determining where the greatest deposition occurred along an arc, the meters could not distinguish between the exposure rate due to cloud activity and that due to ground deposition. To guarantee complete sampling of cloud deposition, the fallout collectors were allowed to sample even after cloud tracking aircraft indicated that the cloud had passed.

Table 2. Exposure rate measurements 3 ft above collectors.

		Collector placement			Collector retrieval		
Location (clockwise)	Fallout collector	Exposure rate (mR/hr)	Date	Time	Exposure rate (mR/hr)	Date	Time
Arc 1	S43[b]	0.50[a]	8 Dec	1110	0.80	8 Dec	2025
	S31[b]	0.30[a]		1120	0.90		2000
	S49[b]	0.30[a]		1130	0.50		1930
	S34	0.40[a]		1140	0.40		1915
	S50	0.40[a]		1140	0.40		1915
	S37	0.25[a]		1200	0.45		1810
	S42	0.30[a]		1215	0.65		1740
	S93	0.009		0745	2.0		1730
	S2	0.010		0820	10.[c]		1705
	S86[b]	0.012		0900	50.[c]		1500
	S12[b]	0.009		0840	15.[c]		1645
	S92[b]	0.012		0845	70.[c]		1520
	S81[b]	0.012		0820	130.[c]		1535
	S17[b]	0.009		0855	10.[c]		1610
	S82[b]	0.012		0855	12.[c]		1615
	S45[b]	0.012		0855	13.[c]		1605
	S79	0.012		0920	8.[c]		1635
	S9	0.010		0915	0.014		1555
	S69	0.010		0740	8.[c]		1650
	S38	0.008		0930	0.009		1535
	S74	0.007		0720	8.[c]		1715
	S24	0.009		0950	0.009		1520
	S67	0.008		0700	3.[c]	9 Dec	0715
	S61[b]	0.007		0640	3.[c]		0740
	S56[b]	0.010		0620	3.[c]		0715
Arc 2	S32[b]	0.007	8 Dec	1305	0.009	8 Dec	2115
	S14[b]	0.007		1230	0.015		2135
	S25	0.008		1205	0.007		2205
	S30	0.008		1205	0.007		2205
	S10	0.006		1135	0.050		2245
	S60	0.007		1105	0.060		2300
	S7	0.007		1035	0.150		2330
	S51	0.005		1000	0.070		2355
	S83[b]	0.009		1235	0.060	9 Dec	1105
	S77[b]	0.009		1213	0.075		1042
	S20	0.005		0910	0.040		1235
	S84	0.005		0915	0.060		1250
	S80	0.005		0915	0.060		1250
	S76	0.004		1003	0.15		1325

Table 2. (Continued)

Location (clockwise)	Fallout collector	Collector placement: Exposure rate (mR/hr)	Collector placement: Date	Collector placement: Time	Collector retrieval: Exposure rate (mR/hr)	Collector retrieval: Date	Collector retrieval: Time
	S78	0.006		1020	0.10		1350
	S36	0.007		1046	0.045		1405
	S88	0.007		1040	0.030		1040
	S98	0.006		1110	0.030		1050
	S100	0.006		1352	0.45		1120
	S89	0.005		1147	0.60		1145
	S85	0.005		1208	0.35		1202
	S96	0.005		1325	0.40		1202
	S91[b]	0.008		1257	1.1		1222
	S87	0.008		1240	0.10		1240
Arc 3	S26[b]	0.007	8 Dec	1443	0.016	9 Dec	0820
	S6	0.008		1403	0.015		0912
	S23	0.008		1518	0.017		0940
	S18	0.008		1518	0.016		0940
	S39	0.008		1310	0.023		1114
	S33	0.007		1235	0.016		1149
	S16[b]	0.008		1200	0.025		1225
	S4[b]	0.006		1030	0.030		1157
	S5	0.005		1100	0.011		1115
	S47	0.009		1130	0.012		1100
	S90	0.006		1445	0.060		1245
	S73[b]	0.005		1405	0.080		1208
	S72	0.007		1325	0.025		1130
	S63	0.007		1240	0.18		1034
	S62	0.007		1240	0.18		1039
	S54	0.006		1150	0.16		1000
	S53[b]	0.006		1115	0.25		0915

[a] Fallout sampling began after arrival of leading edge of cloud.

[b] Sample was radiochemically analyzed.

[c] Monitoring equipment was contaminated by particulate deposition from cloud.

Radiochemical Analysis of Fallout Samples

After the fallout samples had been returned to LRL, each sampling sheet was placed in a gamma counter to estimate its level of contamination. Based on this information, the location of the collector relative to measured ground deposition, and the path of the radioactive cloud, 16 of the 80 sheets were selected to undergo wet chemical analysis for radionuclides of interest.

ANALYSIS PROCEDURES

(1) Sample Preparation

The contaminated polyethylene sampling sheets were unfolded and mounted on a wooden frame. The petroleum jelly, together with the radioactive debris, was washed off with chloroform using squeeges and disposable wipes. Figure 6 shows the washing procedure in progress. The area of the sheet scrubbed down was 5 by 7 ft. By using an area smaller than actually exposed to fallout, it was possible to have a well-defined area for each sheet and to prevent any of the contact cement on the edges from washing into the chloroform. The chloroform, debris, and disposable wipes were then collected in a 4-liter glass beaker.

In order to determine the efficiency of this washing process, the gamma radiation spectra of several sheets were taken before and after washing. The results

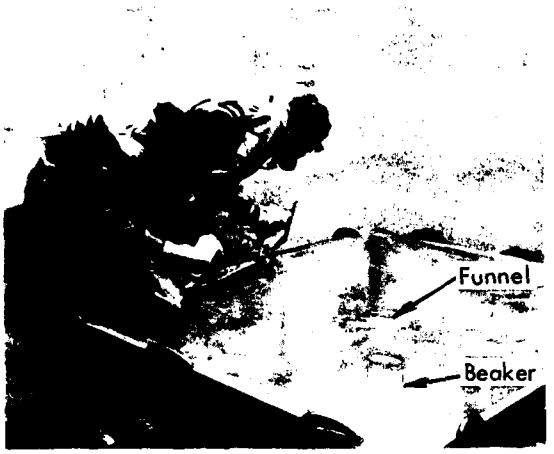

Fig. 6. Procedure used to remove fallout from sampling sheet.

showed only a small amount of activity remaining on a collector after washing. Some of this activity was probably on the backside of the sheet, since backside contamination cannot be prevented in field operations.

The debris and disposable wipes were filtered through a 24-cm filter (Whatman No. 1) into a 1-liter graduated cylinder. A small portion (2 to 5 mg) of I_2 carrier was added to the chloroform to assure retention of ^{131}I leached into the liquid. The total volume of chloroform was determined, and an aliquot was analyzed for ^{131}I with a NaI(Tl) crystal. The filter and wipes were compressed into a 10-cm Petri dish for gamma-ray spectral analysis using a Ge(Li) diode. All gamma-ray spectral data were later normalized to the wet chemical results.

At all times during the preparations, the samples were treated as low-level samples. All equipment used was new, and a separate set of equipment was used for each sampling sheet. The metal clamping frame was cleaned before each sheet was scrubbed. Background samples were processed and showed no measurable contamination.

(2) Dissolution

The aliquot of chloroform and the particulate material were combined with the remaining chloroform in the original beaker and heated to evaporate the chloroform. The paper and some debris were dissolved in fuming HNO_3 and $HClO_4$. Upon completion of this step, the contents of the beaker, both liquid and debris, were transferred to a platinum crucible and boiled to dryness. To complete the dissolution of particulate matter, the residue was treated with HF and $HClO_4$, then 6 M HCl was added to the residue and boiled. The solution was centrifuged, and the liquid was transferred to a flask containing a known quantity of each carrier solution for which radiochemical analyses were to be performed. If any precipitate remained, it was transferred to the crucible and the process for dissolving particulate matter was repeated until no precipitate or activity remained in the centrifuge cone.

(3) Radiochemical Analyses

The clear solution from the dissolution step was divided to produce two duplicate samples. Nitric acid was added to each sample to precipitate tungsten. The liquid was boiled to reduce its volume, and then it was made basic with NaOH. Sodium carbonate was added to precipitate $BaCO_3$ and $SrCO_3$. Cesium was extracted from the basic liquid with BAMBP*-in-cyclohexane. The $BaCO_3$—$SrCO_3$ precipitate was dissolved and HCl

*BAMBP is 4-sec butyl—2 (α-methylbenzyl) phenol.

was added to precipitate $BaCl_2$. The solution was cooled in an ice-bath to enhance precipitation. The solute and precipitate were transferred to an anion exchange resin (Bio-Rad, Ag 21K) column. The strontium passed through the resin and the $BaCl_2$ was recovered by washing the resin with water.

Each element was then submitted to the radiochemical purification procedure[5] used in the Radiochemistry Division for that element.

(4) Counting Procedures

The purified samples were counted on low-background beta proportional counters capable of measuring less than 1 count/min. The results of the counting procedure were used as input to a computer program which made a least squares analysis of the beta decay curves. All decay curves were extrapolated back to the Schooner detonation time.

The Ge(Li) diode spectra were computer-analyzed for radionuclide identification and quantitative evaluation. Because the spectra were obtained in a poor geometry for counting, the final spectral numbers for each sample were normalized to the respective numbers for ^{140}Ba which were obtained by wet chemical analysis. Several of the data from Ge(Li) diode spectra have 10 to 20% precision due to low disintegration rates.

RADIOCHEMISTRY RESULTS

The results of the radiochemical analysis were converted to units of ground deposition (pCi/m^2) and are given in Table 3.[6] The precision of these analyses (including the scrubbing operation) is estimated to be ±10 to ±20% for those nuclides which were most abundant in the debris. Table 3 summarizes these data. Since ^{131}I could have been lost during several of the processing steps, only lower limits for deposition can be specified. Lower limits are also given for samples, S-31 and S-49, because the cover sheet for these samples was removed after the cloud had already arrived so that sampling was incomplete. A comparison of the deposition on two fallout collectors placed side-by-side at the sample location shows that the measurements agree within the specified limits of precision.

Although the maximum error in the radiochemical analysis is 20%, how well the far-out fallout collector actually samples and retains cloud deposited debris is not known. However, the fallout collector was designed and placed to minimize perturbations in the local micrometeorology. Also, a sticky petroleum surface was used to increase the retentivity of the sampling area. As far as resuspension of Schooner debris by wind and its subsequent redeposition on the collector is concerned, this process requires a period of time long in comparison to the actual sampling period.[7] We consider the measured deposition to be within a factor of 2 of actual deposition.

Table 3. Summary of Schooner far-out fallout data.

	Arc 1								Arc 2			Arc 3				
A. Sample Identification																
	S31[a]	S49[a]	S12	S42	S81	S82[b]	S45[b]	S56	S14	S77	S91	S26	S16	S4	S73	S53
B. Location from Surface Ground Zero																
Distance, km	89	90	70	70	65	75	75	108	246	259	278	370	440	385	500	435
Azimuth, deg	357	2	47	47	50	58	58	83	5	32	59	1	17	30	46	56
C. Measured Activity per Unit Area Normalized to Schooner Detonation Time, pCi/m^2																
^{51}Cr	>1.7 (3)[c,d]	—[e]	2.0 (5)	≤1.6 (5)	—	3.0 (4)	≤1.9 (4)	—	—	≤4.0 (2)	6.1 (3)	—	—	—	—	≤2.2 (3)
^{54}Mn	>3.7 (2)	>1.5 (2)	8.0 (4)	8.3 (4)	2.1 (5)	9.8 (3)	8.6 (3)	—	—	1.3 (2)	1.8 (3)	—	—	—	2.0 (2)	7.8 (2)
^{57}Co	>2.2 (2)	>7.6 (1)	4.0 (4)	4.0 (4)	1.0 (5)	5.1 (3)	3.8 (3)	—	—	6.9 (1)	7.4 (2)	—	—	—	7.8 (1)	3.3 (2)
^{58}Co	>1.4 (3)	>5.5 (2)	2.6 (5)	2.5 (5)	5.7 (5)	3.2 (4)	2.6 (4)	—	—	4.9 (2)	5.6 (3)	—	—	—	5.7 (2)	2.2 (3)
^{74}As	>4.1 (3)	>1.8 (3)	3.2 (5)	2.6 (5)	—	4.3 (4)	4.2 (4)	—	—	1.3 (3)	1.1 (4)	—	—	—	1.3 (3)	4.6 (3)
^{88}Y	>2.1 (2)	—	5.7 (4)	5.4 (4)	1.2 (5)	6.6 (3)	5.4 (3)	—	—	≤7.5 (1)	1.2 (3)	—	—	—	1.6 (2)	≤5.1 (2)
^{89}Sr	>3.3 (3)	—	—	1.8 (4)	4.7 (4)	—	—	5.1	3.1	2.0 (2)	1.1 (3)	1.5 (1)	1.8 (1)	2.5 (1)	2.9 (2)	6.3 (1)
^{90}Sr	>6.2	—	—	1.2 (2)	3.3 (2)	—	—	<3	<3	<3	7.5	<3	3	<3	4.6	6.7
^{95}Zr	>1.2 (2)	—	3.2 (4)	2.9 (4)	7.9 (4)	4.3 (3)	3.3 (3)	—	—	5.9 (1)	6.9 (2)	—	—	—	≤7.3 (1)	3.6 (2)
^{103}Ru	>2.5 (3)	>9.5 (2)	1.9 (5)	1.6 (5)	—	2.4 (4)	2.7 (4)	—	—	5.9 (2)	6.3 (3)	—	—	—	8.3 (2)	2.3 (3)
^{110m}Ag	—	—	≤1.2 (4)	≤9.5 (3)	≤2.9 (4)	≤1.4 (3)	≤9.7 (2)	—	—	—	≤3.7 (2)	—	—	—	—	—
^{131}I	>6.8 (3)	>3.3 (3)	≥8.2 (5)	≥5.9 (5)	—	≥1.0 (5)	≥1.2 (5)	—	—	≥1.9 (3)	≥2.4 (4)	—	—	—	≥3.3 (3)	≥7.9 (3)
^{134}Cs	—	—	—	1.9 (2)	7.2 (2)	—	—	<1	<1	—	—	<1	<1	<1	—	—
^{137}Cs	3.4 (1)	—	—	1.9 (2)	7.0 (2)	—	—	<1	<1	3.5	3.5	<1	<1	<1	1.5	3.2
^{140}Ba	>2.7 (3)	>2.3 (3)	2.7 (5)	2.6 (5)	—	4.5 (4)	3.8 (4)	—	—	7.1 (2)	1.1 (3)	—	—	—	1.1 (3)	2.6 (3)
^{141}Ce	>7.5 (2)	>2.7 (2)	9.5 (4)	7.5 (4)	1.8 (5)	1.1 (4)	8.8 (3)	—	—	1.8 (2)	1.9 (3)	—	—	—	2.2 (2)	1.0 (3)
^{168}Tm	>8.6 (1)	—	≤2.3 (4)	2.3 (4)	5.6 (4)	2.5 (3)	2.2 (3)	—	—	≤4.0 (1)	3.7 (2)	—	—	—	≤4.7 (1)	≤2.2 (2)
^{182}Ta	—	—	5.8 (4)	4.8 (4)	—	5.0 (3)	4.6 (3)	—	—	—	9.1 (2)	—	—	—	—	—
^{181}W	>8.6 (5)	>3.3 (5)	6.5 (7)	3.9 (7)	1.2 (8)	8.8 (6)	7.2 (6)	1.7 (3)	≤2.5 (1)	1.9 (5)	2.0 (6)	—	6.8 (3)	2.7 (4)	2.3 (5)	6.3 (5)
^{185}W	>2.6 (6)	—	—	1.1 (8)	3.2 (8)	—	—	4.5 (3)	≤8.1 (1)	5.3 (5)	5.3 (6)	—	1.8 (4)	7.4 (4)	7.0 (5)	1.9 (6)

[a] Sampling began after arrival of the cloud's leading edge, so only lower limits may be specified.

[b] Sample was 1 of 2 placed at the same location.

[c] 1.7 (3) is equivalent to 1.7×10^3.

[d] *An underlined quantity signifies that the error of* radiochemical analysis was 10 to 20%, rather than less than 10%.

[e] A dash means that the presence of the nuclide in a sample could not be established.

Conclusions and Recommendations

The Far-Out Fallout Collection Program was successful in documenting the magnitude and extent of fallout up to 500 km from the Schooner SGZ. From preshot collector fabrication, through field planning and operational control at detonation time, to sample recovery and subsequent analysis in the laboratory, a practical and efficient program has evolved to measure fallout at large downwind distances.

Although it did not rain or snow during the fallout sampling period, the field program should be expanded to incorporate the capability of sampling debris deposited by precipitation.

On future cratering events a concerted effort should be made to obtain fallout samples at downwind distances that correspond to about a 24-hr cloud travel time. At these distances, long-lived fission products cannot be detected; however, their presence could be inferred from shorter-lived, similarly behaving induced radionuclides. Data at these extreme distances would be helpful in refining and improving present prediction techniques.

Acknowledgments

The authors are indebted to many people whose efforts helped to make the Far-Out Fallout Collection Program successful. Larry Schwartz of the Radiochemistry Division of LRL was responsible for the preparation and analysis of the fallout samples. John Lane of the K Division of LRL directed the fabrication of the fallout collectors. Charles Costa of USPHS-SWRHL coordinated the logistic support for field operations. Barclay Andrews and Jerome Lattery of NCG and Charles Costa supervised and directed the field operations. Many tedious hours were spent in the field placing and retrieving the fallout collectors by the following people: W. Corkern, S. Body, D. Branca, P. Fitzpatrick, M. Gordon, T. Grady, N. Matthews, D. Moden, D. Odson, C. Rizzardi, R. Smiecinski, R. Sullivan, all of USPHS-SWRHL, L. Corsiglia, J. Cress, and A. Sowers of NCG, and S. Young and R. Lucido of the Bio-Med Division of LRL.

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